Appendix

Appendices to part A and B

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I. Historic development Eastern Scheldt

I.1 Eastern Scheldt basin

As can be seen in Figure I.1, in the east basin there are many intertidal shoals and flats, and in the south two small salt marshes Rattekaai and Krabbendijke can be found.



Figure I.1 Names of flats and channels in the east branch of the Eastern Scheldt basin.

I.1.1 Formation of basin

During the last ice age, the sea level was lower and the North Sea was dry. The river Scheldt had its outflow into what are now known as the Rhine and Meuse rivers. During the Holocene temperatures and sea levels rose, turning the low lying areas of Zeeland into an intertidal area around 6700 BC. As the sea level rose too fast for sediment deposits to keep up, lagoons formed behind sand bars. Around 5500 BC, the Scheldt changed its outlet directly to sea. At this time, more than half of Zeeland had turned into intertidal or peat area, that could now, due to reduction in the rate of sea level rise, keep up with the sea level rise. Around 4400 BC, the land started to accrete above the water level and in 1800 BC, most of the delta was covered with a thick layer of peat with the Scheldt flowing through this peat swamp (Hesselink, Maldegem et al. 2003). (Figure I.2)

In Roman time (+- 200 AD), humans settled in this swamp, digging ditches to drain the peat. The drainage, together with the removal of peat, resulted in settlement turning the area back to intertidal land. The Southwest delta became more an area with large intertidal areas with channels cutting through peat layers and large entrances to the North Sea. The outflow of the Scheldt became wider and around 750 AD, a connection between the Scheldt and the Western Scheldt entrance was being formed and slowly became the main outlet branch of the river Scheldt. The connection to the Eastern Scheldt slowly silted up (van der Spek 1997).

In the Middle ages (1200 AD), construction of the first dykes started, resulting in protected area's from the sea that settled far below sea level. This meant that, when a dyke breakthrough occurred, the low lying land behind was often permanently lost to the sea. (Hesselink, Maldegem et al. 2003)



Figure I.2 Historic development of the South West Delta, from (de Bok 2001)

I.1.2 Eastern Scheldt system

In the Eastern Scheldt bathymetry, the channels have a braiding pattern (Van Veen 1950). Van Veen also sketched flood and ebb channels in the historic Eastern Scheldt basin and described the forking and flanking behavior of ebb and flood chutes, Figure I.3.



Figure I.3 Hydraulic system of Eastern Scheldt 1932-'37 (Van Veen 1950)

I.1.3 Verdronken land van Zuid Beveland

St Felix flood (5 November 1530)

Major flooding of the low-lying land behind dykes occurred in 1530, during the Saint Felix flood. A large area $(\pm 95 \text{ km2})$ presently called the 'Verdronken Land Zuid-Beveland', see Figure I.4, was inundated (Eelkema, Wang et al. 2009), creating the large basin in the east still present today (Figure I.4). Due to the increase of the basin area, the tidal prism increased and as a result the cross-sectional area of the channels in the entrance increased.

The Scheldt river discharged more and more through the Western Scheldt. In 1867, the connection between the Eastern and Western Scheldt was dammed. Inpoldering and the construction of a train dyke, meant that the Eastern Scheldt was completely cut of from the Western Scheldt. The former Eastern Scheldt estuary, now having no major river inflow anymore, was almost a tidal basin with only some of the Rhine water discharging into the basin. (de Bok 2001; Saeijs, Smits et al. 2008)



Figure I.4 Historical map Kom basin by Visscher Roman (approx. 1650) source; http://zldags.zeeland.nl/Geo/

II.Bathymetry data

This paragraph shows the analysis of the sedimentation-erosion patterns in more detail than described in the report. Subsection II.1.1 investigates the bathymetry changes before the Delta works, between 1968 and 1990. The second section looks at the sedimentation-erosion patterns after the finalization of the Delta project from 1990 to 2010.

II.1 Sedimentation erosion patterns

II.1.1 1983-1990

As construction works started in 1958, this period is influenced already by the Delta plan. The main impact is an increase in tidal prism due to the Grevelingendam and the Volkerakdam. The start of construction with a work island for the Oesterdam had local influences in the East branch of the basin. During this phase, three bathymetry data sets are available namely; 1968, 1983 and 1990.

Between 1983 and 1990 the tidal prism and tidal range already decreased due to the Delta works, see Table II.1. This could explain why the intertidal area's were loosing height in this stage. Especially the high Hooge Kraaijer flat and the Loodijke flat showed erosion, see Figure II.1.

In the former ebb chute (van Gessel 1974) named Zilverput, sedimentation occurred. There still seemed deposition in the outer bend of the large channels and on the flood chute that flows onto the Lage Kraaijer. Conclusions on this have to be stated carefully, as it is possible that the data contains errors.

Kom	1968	1980-1984	1987
Tidal range (cm)	369	398	340
Bergsediepsluis			
Tidal prism (Mm3)	530	425	290
Yerseke			

Table II.1 Changes in tidal range and tidal prism between 1968 to 1987 in the 'Kom' (Vroon 1994)



Figure II.1 Changes in bathymetry between 1983 and 1990, showing erosion(blue) and sedimentation (red) patterns.



Figure II-2 Sedimentation(red) – Erosion(blue) patterns during 1990 to 2001in meters



Figure II-3 Sedimentation(red) – Erosion(blue) patterns during 2001 to 2010 [m]

II.1.2 1990-2001 & 2001-2010

During this phase the Delta works have had a true impact. The tidal prism and tidal range have reduced and the effects of the sand deficit of the basin will be visible. In this stage four different bathymetry datasets have been measured in 1990, 2001, 2007 and 2010. Two phases with respectively 11 years (1990-2001) and 9 years (2001-2010) are considered.

1990-2001

Erosion is present on all intertidal flats in Figure II-2 and sediment is deposited in the channels and small gullies on the flats. The erosion seemed highest on high exposed locations of Loodijke, near Yerseke and on the highest location on the Hooge Kraaijer flat.

The channels show an increase in height (red). Near Tholen the deep channels show large sedimentation. Also the Marollegat and Mosselkreek channels in Figure II-2 show an overall red pattern, meaning that sediment has deposited in these channels. The deeper Zilverput location, that before the construction of the Oesterdam used to be a flood chute (van Gessel 1974), also experiences sedimentation.

The figure also shows some possible errors in the bathymetry data. The chessboard patterns and the strange patterns around small channels in direction of ship tracks are not realistic. Also some of the flight tracks in Northwest to Southeast direction can be noticed on the Rattekaai saltmarsh.

2001-2010

Figure II-3 shows that the erosion on the flats seems to be less than in the period between 1990 to 2001. The erosion rate on the Oesterdam flat stays high.

This reduction of erosion might be due to several factors;

- Time period considered is shorter
- Different weather conditions
- Actual reduction erosion rate, erosion gives lowering of shoals resulting in less wave impact on bottom

- Actual reduction erosion rate, due to uncovering of less erosive peat layer The channels show some red, indication sedimentation. Again this is not as clear as in Figure II-2, probably because less eroded sediment would have been available to settle. The erosion of the Oesterdam flat and the sedimentation in the adjacent Zilverput, North of the Oesterdam flat, are both still relatively high.





Figure II-4 Sedimentation erosion [m] between 2001-2007

Figure II-5 Sedimentation erosion [m] between 2007-2010

Just as the previous stage, also in these bathymetry data sets some errors are present. The chess board patterns are even more prominent, especially in the deep channels section. Also the opposite behavior of the Rattekaai saltmarsh in the two stages in Figure II-4 and Figure II-5 points to an error. The same holds for the flat between Yerseke and Krabbendijke. These figures show that the error band of the bathymetry data is approximately 0.2m.

II.2 Volume balance analysis (1990-2010)

In this paragraph the results of the volume analysis are presented. Firstly the results of polygons defined in the entire Kom basin will be shown. After which the project area near the Oesterdam will be investigated in more detail.

II.2.1 Polygons

In the east branch 9 polygons are investigated, presented in Figure II-6. These have been defined in such a way that similar morphogical behavior is expected within these area's. In total 4 intertidal areas and 4 channels have been assigned.



Figure II-6 Polygons in Kom basin

II.2.2 After storm surge barrier 1990-2010



Figure II-7 Volume development channel polygons



Figure II-8 Volume/ Area development tidal flat polygons

Clearly the flats are loosing sediment, as can be seen in Figure II-8. Note that the change in sediment volume has been divided by the polygon area, resulting in change of height in meter. In this way the overall trends of loss over the different sizes polygons can be seen. The Hooge Kraaijer and the Southern Flats show the highest erosive trends, the latter polygons contains errors, see II.1.2.

The channels are gaining sediment, shown in Figure II-7. However, the balance over the entire Kom polygon is not closed, sediment volume seems to be lost (Figure II-9). Not all sediment that is eroded from the flats can be found back deposited in the channels. Question remains what is the explanation for this. It could be that the erosion is overpredicted by the data or the sedimentation underpredicted. Or that the sediment is transported out of the Kom system.



II.2.3 Volume Loss Kom basin

Figure II-9 Volume balance Kom channels and Flats

The Kom seems to be loosing 11Mm3 between 1990 and 2010. This is not realistic. It is unlikely that this large amount of volume would be transported out of the almost closed domain, especially since the transport capacity of the channels has been reduced as effect of the reduced tidal currents.

However, as it is a continuous trend in bathymetry data it is also not possible to ignore. Note that the rate at which sediment is lost is showing abrupt decrease between 2007 to 2010. Possible causes, hypothesis for the volume loss are;

- Error in bathymetry data However, as this trend is continuous it is not a simple mistake in bathymetry height. It could be that the deposited sediment in the channels is not measured accurately. The channels have very steep sides, reducing accuracy of measurements.
- Compression of subsurface peat layer Question is; why did this not happen before storm surge barrier?
- Decomposition of surface peat layer
 As the peat layer is uncovered, it comes in contact with air and water. This could
 result in decomposition of the peat layer. Question is, is it dissolved or does it
 decompose into small particles that should settle somewhere.
- 4. Human interventions (dredging, oystershell removal) There is no record of large continuous dredging activities. The oyster fishery does remove dead oyster shells from their plots. However, not these large amounts.
- 5. Real trend

It could be that the trend is real and sediment is transport out of the Kom basin. History shows that this basin has been importing and exporting sediment before, however, if this was the case it must be found somewhere in the Eastern Scheldt basin. Research of Haskoning (2008) has not shown this.

II.2.4 Royal Haskoning sand balance vs 'vaklodingen' sand balance

In the Royal Haskoning report (Royal 2008), also sand balances of different area's in the Eastern Scheldt were made. A comparison between these two results, will give insight into the reliability of both analysis.

The two researches show similar trends and order of magnitudes for both analysis, Table II.2. Because the exact size and locations of the polygons are different, the magnitudes are not exactly the same. Because the polygons compared do not cover the entire area of the Kom, the sum of the polygons is not exactly equal to the trends found in the entire Kom.

The trend of the Kom basin loosing sediment continues in the new data set. However, the rate of this loss reduces greatly. Between 1990 to 2007 the Kom was loosing -0.67Mm3/year. In the last 3 years, the Kom has lost sediment volume at a rate of -0.07Mm3/year. Realize that this trend is only present in one data set (2010).

Haskoning	6	7	8	35		
	Verdonken	Hooge		Channels		
	land van ZB	Kraaijer	Speelsmansplaten	Kom	KOM	
Totalen	Netto	Netto	Netto	Netto	Netto	
Units	[Mm ³]	[Mm ³]	[Mm ³]	[Mm ³]	[Mm3]	[Mm ³ /y]
2001-1990	-4,9	-1,1	-1	1,1	-6,5	-0.59
2007-2001	-2,2	-0,6	-0,7	-0,2	-3,1	-0.52
2007-1990	-7,1	-1,7	-1,6	0,8	-9,6	-0.56
<u>Vaklodingen</u> (this research) <u>Mm3</u>	SouthernFlats Kom	Hooge Kraaijer	NorthernFlats Kom	Channels Total	Kom	
Units	[Mm ³]	[Mm ³]	[Mm ³]	[Mm ³]	[Mm ³]	[Mm ³ /y]
2001-1990	-5,47	-1,02	-1,30	0,76	-8,08	-0.73
2007-2001	-2,63	-0,42	-0,57	0,54	-3,35	-0.55
2007-1990	-8,10	-1,45	-1,87	1,30	- 11,43	-0.67
	0.44	0.00	0.00	0.55	0.00	0.07
2007-2010	-0,41	-0,22	-0,06	0,55	-0,22	-0.07
2001-2010	-3,05	-0,64	-0,64	1,09	-3,58	-0.40
1990-2010	-8.52	-1.66	-1.94	1.85	۔ 11,66	-0.58

Table II.2 Sand balance in Mm3 from Haskoning (Royal 2008) and this research

II.3 Erosion rates per polygon

The erosion trend in Figure II.11 found when considering the volume balance of a polygons, show a slightly lower erosion rate. The erosion rate varies between -1.2 and -1.6 cm/y. An average value of -2 cm/y is taken as a high erosion rate scenario.

All polygons on intertidal flats in the project area are loosing sediment. The Oesterdam flat is loosing sediment fastest. This flat has lost 33 centimeter in 20 years time. When assuming that the erosion rate has been constant this gives an overall trend of height loss of -1.65 cm per year.



Figure II.10 Erosion rates Kom basin between different stages from 1990 to 2010.



Figure II.11 Trend Lines for erosion rate in cm/y for project area

III. Stakeholders+Ecology

III.1 Stakeholder analysis

There are many parties with a stake in the Eastern Scheldt basin. All with specific demands from the system; commercial (oyster)fishery, recreation (spitters, divers, wind surfing), safety (RWS, waterboards, province of Zeeland) and nature (nature organizations). The stakeholders in the Oesterdam project have been identified and grouped according to their usage of the system.

III.1.1 Shellfishery & spitting



Figure III-1 Users in Kom basin. [ftp ANT(Deltares 2011)and other map, where purpe with raster=mechanical spitting] from rwsgeoweb.nl

Oyster plots (commercial)

In the Eastern Scheldt there is a large shellfish industry. The basin is used for cultivating and harvesting shellfish as cockles, mussels and oysters. In the Kom mainly oyster plots are present (blue plots in Figure III-1).

On these plots mainly Pacific oysters are breed. On the plots the 'oesterkweker' has layed hard structures such as old mussel shells on which the small oyster larvae can settle in July and August. In May, the young oysters are collected and replaced on new plots. During the growing of the oysters, the farmer replaces them to other plots two times a year to ensure a large and oval shaped oyster. When they are full-grown (pacific oyster after 3yrs) the fishermen harvest them. Near Yerseke many 'verwater' plots are located. Oysters are placed here after they have been harvested to filter out sediment, to adapt oysters to dry conditions for transport and as storage location. It is important that the water quality at these 'verwater' plots is good.

(zeeuwseoesters.nl and np-oosterschelde.nl)

The oyster fishery has no benefit in this project. Oysters are grown in relatively deep water, these areas would even increase with sandhunger. Also, they are afraid of the nourishment disturbing their plots. Sediment transported, oysters get buried. Or at least, not good quality oyster with sand. Turbidity.

Spitten (by hand and machine (commercial?))

The tidal flats in the Eastern Scheldt are used by sportfishermen to find their bait (worms). Sufficient and good 'spit gebied' must remain in the Eastern Scheldt. The project location is currently a spit location. If the nourishment covers the current intertidal area, 'pieren' are buried and it will take a long time before they will re-colonize the foreshore (Westdorp 2011). If the conditions at the foreshore are altered by the nourishment it remains a question if the worms would even return. A good solution might be the reallocation of the spit area.

III.1.2 Nature organizations

The Eastern Scheldt basin is a valuable habitat. This means that the basin has several different parties and policies that are involved or have to be applied. The involved parties are considered stakeholders.

National Park

The entire Eastern Scheldt basin is assigned as a national park. (natuurpark.nl). This means that many parties have united in one group (np-oosterschelde.nl). Among these parties are; LNV, RWS, Provincie Zeeland, Waterschap, several city councils, Staatsbosbeheer, Stichting het Zeeuwse Landschap, Vereniging Natuurmonumenten, others incl IVN and private land owners.

The national park is trying to save intertidal area. Project is beneficial for them. They want to create more intertidal area and they want to get knowledge what is best way.

Program 'Klimaatbuffers' and Natuurmonumenten

Natuurmonumenten is a nature organization that acquires and preserves currently 355 nature conservation areas with a total surface of over 100.000 ha. The 'Verdronken land van ZB-land' is one of these areas. (natuurmonumenten.nl)

Natuurmonumenten is also initiator and financer for the Oesterdam project. Through the program 'Natuurlijke Klimaatbuffers', this program entails the collaboration of seven nature organizations, among which Natuurmonumenten. (klimaatbuffers.nl)

Same as national park. Also interested in intertidal habitat and knowledge.

III.1.3 Safety and policies

Rijkswaterstaat (Dienst Zeeland)

Rijkswaterstaat (RWS) is the dutch governmental organization that is responsible for the design, construction, management and maintenance of all the infrastructure and primary water barriers in the Netherlands. The Dienst Zeeland is responsible for the primary water barriers in Zeeland. The Oesterdam is the responsibility of RWS Dienst Zeeland (DZL) and the Oesterdam Safetybuffer is therefore a project from RWS DZL.

Project bureau Zeeweringen (RWS and Scheldestromen)

Project bureau Zeeweringen (zeeweringen.nl) Is a collaboration between Waterschap Scheldestromen and Rijkswaterstaat to carry out the necessary renewal of the revetments on the dykes surrounding the Eastern Scheldt. The south part of the Oesterdam is one of these projects where the revetment is being replaced.

Other stakeholders are;

- Province of Zeeland and Ministry of I&M
- Waterschap Scheldestromen

III.1.4 Shipping

Through the Bergse Diep Sluis in the north of the Oesterdam, mainly recreational shipping takes place. The Schelde-Rijn channel, behind the Oesterdam, is an important shipping route between the ports of Antwerp and Rotterdam. (Schefferlie 2008)

Ships do not experience major effects from the project. Only due to busy shipping lanes maybe some disturbance can occur. It might be possible to create 'work with work' by using dredged material from shipping routes as nourishment. Depending on the quality, grain size and location of the dredging activities.

III.1.5 Recreation

Swimming and surfing

The location 'Oesterdam Westzijde' (Dewitte, Buuren et al. 2008; Rijkswaterstaat 2008) is mainly used by surfers, there is hardly normal swimming activity. Kite surfers and wind surface use the Oesterdam location because the Oesterdam provides easy access and shallow waters. A remark on oysterbeds is made where surfers have injured their feet. On a good day almost 300 kitesurface can be found on the location, on an average day about 50 windsurfers are present.

During construction, the windsurfers will probably have limited access to the area. But after finalization not much will have changed for the surfers, depending on the design of the nourishment and if no nature zoning will be applied.

Diving

North of the Bergse Diep sluice there is a well known diving location (Bergse Diep location 9). This location is far away from the project location that there are no effects for the diving activities.

Culture/archeology

The 'Verdronken land van ZB-land' is a historic polder that has been flooded. Many old farms and other structures can be found buried or at the surface of the intertidal flats. As far as is known today, no important archeological structures are located at the project location (zldags.zeeland.nl/geo/). This would mean that there is no effect on the project. However, the possibility of an important structure being uncovered by changing currents or conditions must be kept in mind.



III.2 Ecology

III.2.1 Policies and regulations

The Eastern Scheldt is very valuable nature area, it is both a national park and a natura2000 area. Especially the ecology on the intertidal flats is of great value. On these flats benthic species are food for wader birds during low tides.

The loss of intertidal flats means loss of these species. The Oesterdam project focuses mainly on 'scholeksters' because they show decreasing trend in Kom basin. Natura2000, National Park).

Natura2000 and Ecologische Hoofd Structuur (EHS)

The Eastern Scheldt is assigned as a Natura2000 area. This means that the (vogel- and habitatrichtlijnen) birds and habitat directives have to be applied for this area. As assigned by EU. Natura2000 areas are locations that have been assigned by EU to be of large ecological value. They are defined by the European bird and habitat directives. In the Netherlands 160 areas assigned as Natura2000, all of these are within the Dutch Ecologische Hoofd Structuur (EHS). (Natura2000.nl)

III.2.2 Species

Oystercatchers are the bird species that show a decreasing trend in the Eastern Scheldt. The nourishment will have to provide good foraging location for this species. Oystercatchers have small shrimps and cockles as their favorite food.

Most important benthic species that serve as food for wader birds.

Wader bird species are important species. They feed during low water on the dry fallen intertidal shoals. The benthic species living on these intertidal areas serve as their food.

III.2.2.1 Scholekster Oystercatchers

These birds mainly 'overwinteren' in the Wadden and Delta areas where they feed on shellfish (cockels and mussels) on the intertidal areas. During breading they can live on fields. But after breading time they feed on intertidal areas and rest at higher quite locations as high sandbanks, saltmarshes or dykes.

They feed mainly on less silty flats. They are 'dominant' and 'plaatsgetrouw' with regards to feeding and resting locations. Meaning that if their habitat is disturbed they can not automatically use other areas, as they might be used by other birds.

The oystercatchers are the only wader bird species that show a decreasing trend, also in the Kom.

III.2.2.2 Kokkel Cerastoderma edule Cockle

The cockles are very important food for the oystercatchers. The cockels can live up to waterdepths of 15m but their optimal habitat is intertidal area. They can withstand an emersion time of several hours. They are most abundant in sediment that are not too fine or too muddy, with average currents.

They live close underneath the surface(adults 5cm, Young up to 20cm deep), using two tubes that stick out of the bottom. One is used to suck water and food in and the other to blow out the filtered water and waste. The tubes have light sensors, so they can retract them when a shadow of a predator is approaching. They can withstand salt contents between 15 en 40 ‰. The cockles show a negative trend in the Easter Scheldt (sovon.nl)

IV. Report of Workshop 'Oesterdam suppletie' held on 10th january 2012

IV.1 Workshop background

This report presents the results of the workshop titled; 'Oesterdam suppletie', held on the 10th of January at RWS Zeeland office in Middelburg. The workshop was organized as part of the Master thesis project from Lies de Graaf on the Oesterdam project. The main goal of the workshop was to gather different ideas and arguments behind design choices for the Oesterdam foreshore nourishment. The generated designs are used as input to the Master thesis study.

IV.2 Program and goal

Main workshop goal; The participants are asked to produce ideas and designs for the Oesterdam foreshore nourishment. The challenge is to make three designs that optimize nature, safety or the project goal (combination of safety and nature), where arguments on specific choices in the design are most important.

Program				
14.00 uur	Welkom			
14.10-14.20	Presentation: Oesterdam project (Eric van Zanten)			
14.20-14.45	Presentation: Workshop problem description (Lies de Graaf)			
14. 45-15.30	1st design round; Sandy solutions			
15.30-16.00	Presentations designs (chairman: John de Ronde)			
16.00-16.30	2nd design round; sand + other solutions (e.g. Building with Nature)			
16.30-17.00	Presentations designs 2 nd round			

IV.2.1 Workshop participants

	Name	Organisation
1	John de Ronde	Deltares
2	Dick de Jong	RWS Zeeland
3	Eric van Zanten	RWS Zeeland
4	Dirk van Maldegem	RWS Zeeland
5	Edwin Paree	RWS Zeeland
6	Yvo Provoost	RWS Zeeweringen
7	Carla Pesch	Hogeschool Zeeland
8	Ruud de Boer	Hogeschool Zeeland
9	João Salvador	Hogeschool Zeeland
10	Mindert de Vries	Hogeschool Zeeland/ Deltares
11	Jaap van Thiel de Vries	Deltares/ TU Delft
12	Menno Eelkema	TU Delft
13	Lies de Graaf	TU Delft
	Absent	

Kees van Westenbrugge	RWS Zeeland
Jaap Brilman	Provincie Zeeland
Nicolette Volp	TU Delft

IV.3 1st part - Presentations introducing Oesterdam project

Presentation - Oesterdam project (Eric van Zanten)

Intertidal flats in the Eastern Scheldt are eroding due to the reduced tidal prism since the storm surge barrier. The lowering of shallow foreshore results in higher waves being able to reach the Oesterdam. Besides this expected increase in hydrodynamic loads, the current revetment on the entire Oesterdam stretch is classified unsafe.

The project originated with the idea of strengthening the Oesterdam solely with sand. This initiative has been proposed to the ministry of I&M, after which it has been scaled down to a solution where a new revetment would be combined with a foreshore nourishment of 600.000 m3. The aimed purpose of this nourishment is to restore the height of the foreshore to the situation before the storm surge barrier in 1986. Compensating in this way the loss of intertidal habitat.

The nourishment is also intended to delay the expected necessary maintenance/renewal of the revetment on the Oesterdam by 20/25 years. Increasing it lifetime from 30 years to 50 years.

The project is funded by three different parties namely; Natuurmonumenten (1 Miljoen euro), the Ministry of I&M (1.4 miljoen euro) and by the Provincie Zeeland (125.000 euro).

Remarks/Discussion:

Question from Carla; What is the time planning of the project?

Eric: The planning of the project is ambitious. We aim to start with the construction of the nourishment at the end of 2012 or the beginning of 2013. This means that the design will have to be completed at the summer of 2012.

Presentation – Workshop problem description (Lies de Graaf)

During the Saint Felix flood in 1530 a large part of the Kom, currently known as the 'Verdronken land van ZB' was flooded. Channels in this area are cutting through peat layers, creating steep lopes.

The project area can be divided in three different sections (Information from Edwin Paree), see figure to the right.

- 1. Oesterdam flat: A broad sandy flat in the North. Not much variation in benthic life.
- 2. Kreekrak flat: A narrow flat with a more silty bottom, more variation in benthic life.
- Rattekaai saltmarsh: This saltmarsh lies at the Southern end of the project area. Hardly any erosion is found here and it is a valuable habitat.

The most important users in the Kom are; oyster fisheries and 'pieren spitters'. The area is also a Nature2000 area, intertidal flats are especially important habitat for wader bird species.



The Deltaworks have reduced the tidal prism and hence the tidal currents in the channels of the Eastern Scheldt. Due to this the channels have smaller capacities to transport sediment onto the

shoals. Erosion processes during storm continue unaffected and on average the intertidal areas are loosing sediment. This process is called 'sandhunger=zandhonger'.

This loss of intertidal flats is visible in the bathymetry data of the Kom. However, the 'vaklodingen' datasets show a unrealistically large loss of sediment volume. The erosion rate found (-2 cm/y) provides a possible high erosion scenario. The RTK transect data show much smaller erosion rate and a conservative scenario of -5mm/y is based on these measurements. With a lifetime of 50 years and including sealevel rise, these scenarios show an erosion of 125cm or 50cm.

The effect is that the exposure time of the intertidal flats shortens. Birds will have less time to feed.

An overview of the hydraulic boundary conditions of the project area as presented during the workshop is attached to this report (attachment A).

Discussion/Remarks

Dick; Be careful when concluding that high areas erode fast. Salt marshes are not eroding, there is cliff erosion but this is a completely different process. Only the higher area of the intertidal flats are eroding fast.

Eric suggests to make the goal of the workshop more concrete. It is decided to make at least 3 different designs with specific intentions.

- Safety solution. This design does not contain the new revetment on the dam. It should provide safety with only sand, including the remaining strength of the current dam. Not building the new revetment would save money, so more budget should then be available for the nourishment. That is why a larger sand volume can be used.
- A nature solution. This solution aims not only to have as little negative effects on nature as possible and keeping current nature values, but creating more/better nature. Increasing nature values. For this design, the project area considered may be larger then just the foreshore at the Oesterdam.
- Project solution. This design should be within project frame. Both benefit for safety and nature and within assigned volume (600.000 m3) and project area. And no possibility to create high dry solutions like a dune, as this is not the current nature situation.

IV.4 1st design round - Sandy solutions

The participants form small groups of 3 persons each to work on possible designs, using maps and aerial photographs to sketch their ideas. After 45 min. each group assigned a team member to present their designs.

Groups

- 1) John de Ronde, Ruud de Boer, João Salvador
- 2) Dick de Jong, Menno Eelkema, Mindert de Vries
- 3) Jaap van Thiel, Edwin Paree, Yvo Provoost
- 4) Carla Pesch, Eric van Zanten, Dirk van Maldegem

IV.5 Presentations

Group 1





The design that fulfills the project goals generated by this group is very straight forward. The reasoning behind the decision to make a tidal flat between 100 to 200m wide and 1.25m high is clear. When the highest erosion scenario is chosen, this means that during the lifetime of 50 years, 1.25m of the tidal flat will be eroded. This amount of sediment is therefore added to the current situation over 100m or 200 m width. In this way ensuring that the hydraulic conditions remain equal to the current situation, even after 50 years of erosion. The foreshore will have an overall gentle slope, similar to the current bathymetry in order to create as natural intertidal flat as possible.

Nature variant

This solution is trying to create new saltmarsh area, as this is considered valuable habitat. Saltmarshes might be formed by placing sediment on high areas and creating sheltered locations behind these higher flats where silt could settle.

One of these high areas looks like an island and is placed on the Rattekaai saltmarsh (B). Another is shaped as a spit extending on the Oesterdam flat in the North (A). These higher islands will be about +1m above NAP and they create sheltered area's on the lee side. Because these islands break the waves, erosion along the dam at this sheltered 'shadow' is lower. This means that there the foreshore-nourishment can be narrower, 100m instead of 200m.

The area underneath the southern island remains open, not obstructing the flow. Ensuring that the tide will still be able to flow in and out as is does now.

Along the cross section variation in height can add extra benefit for nature. For example a higher flat with a deeper area behind with water. This will give extra nature value.



Discussion/Remarks

Question from Dick de Jong; What is the function of the island in the Southwest in the nature design? Is it expected that this island creates some sort of benefit for nature?

Answer; Yes, this island is meant as benefit for nature. The area is already relatively high. This means that not much sediment is needed to make a higher area of +1m NAP. The idea was to create different habitats and possibility for saltmarshes to be created in the sheltered lee side of the islands. Dick; No! Saltmarshes will not form in the Eastern Scheldt as there is no silt available for sedimentation. Furthermore the idea of using an island to create a sheltered area will not have much effect. The location is already one of the most sheltered areas in the Eastern Scheldt.

Safety variant

To optimize safety the group has come with the solution of a high nourishment of 200m wide and a height of 3-4m. Against the Oesterdam a high dune is placed that will be eroded during storm conditions throughout the entire lifetime. The eroded sediment will spread across the foreshore. The minimal width to compensate the dune erosion has to be determined/calculated, 50m seems a good first estimate.

The dune foot should start at a height of +3m NAP, or at least above the HWS level. In this way, dune erosion only occurs during high storm levels. Greatly increasing the lifetime of the dune.

With a height of 3 to 4 meter the nourishment will be above high water. This means that the design will create the possibility of a recreational beach along the Oesterdam.



Group 2

Before they started, the group concluded that there is no (or hardly) erosion on the Rattekaai and most of the erosion occurs further North. The chosen project area was restricted to this northern location.

Safety variant

Protecting the dam from waves is the main goal of this design. Further the assumption is made that the current foreshore will be backfilled to the 1986 profile.

Now the consideration was to place a ridge somewhere on this profile. The question remains what is the best location for this ridge? There are two main cross-shore locations; against dam (A) or further offshore (B).

If the ridge is placed right next to the dam (A), waves across the flat will be higher than if ridge is placed further offshore (B). In that way the ridge breaks the waves there and shelters the flat behind. As waves are lower also erosion rates are expected to be less.

When the ridge is located further offshore it also traps the sediment on the flat. However, if the ridge is placed close to the dam foot, the sediment will spread across the foreshore.



There are three possible alongshore locations for the nourishment.

- 1. Close and parallel to dam. This is the most straight forward location and provides safety along the entire stretch of Oesterdam considered.
- 2. Parallel to dam on the Oesterdam flat. This creates a sheltered area behind the ridge where less erosion occurs.
- 3. Cross to dam on north side Oesterdam flat. Assuming that the sand loss from the flat is to the north (see sketch), this design could also act as a sand trap. Also a sheltered area is created south of this ridge.
- 4. A general consideration; what happens if you put the sand instead of in a ridge on flat, in the deep part of the Zilverput north of the flat (location 4). What is the effect? Is it similar as ridge? This will need more sand to fill this deeper area up to the same level.

Nature variant

IV.5.1.1. Ridges

Group 2 came to the conclusion that the ridges from the previous variant are no real bonus for nature. They create no habitat for 'wadpieren'. The ridges might have a positive effect for birds

regarding feeding time. Although, if there is not enough food (worms etc.) available at these ridges the effectiveness is depending on balance between these two.

IV.5.1.1. Worm valley

Another idea from this group to create a nature design was reallocating the 'pierenspitters'. Currently there is a 'spit' location at the broad flat. If the sediment available for this project is used to make the area near the Bergsediepsluis shallower, the pierenspitters can move to that location. The current project location could then be assigned as a nature zone. This would mean an undisturbed area for nature is created, that is a great benefit for nature.



Consideration; Spreading the nourishment works in time and space

A consideration from this group is that zoning the nourishment works in both time and space could also be beneficial for nature, or at least ensures the least amount of impact.

Phasing the project in time can be done by working in different zones or applying the nourishment layer by layer over the entire area. This last method is technically not feasible, because the nourishment would have to be placed in too thin layers. Besides, this method would disturb the entire area during each phase, not allowing nature to restore itself.

The nourishment could also be phased in different zones in space. For example by first applying the nourishment on north side of flat (phase 1). Let this sediment spread over the flat during 10yrs. After



that fill up the rest of the flat to required height (phase 2). This location might have been fed by the previous nourishment.

Group 3

Safety variant

This design consist out of a dam within a high dune in front of it, this can be schematized as a dam within a dune. Before the dune has eroded, it will provide all the safety of the design. As the duneface erodes during storms within the lifetime, the sediment will spread across the foreshore. Creating a growing foreshore area for nature.

After 50 years the (green line) dune is expected to be completely eroded. The sediment has spread cross-shore, creating a high flat in front of the dam. This high flat reduces waves with 50%. The old revetment should still have sufficient strength left to withstand these smaller wave conditions during the design storm.



The most logical location (1) in the project area for this safety design is parallel and close to the dam, as sketched in black in the figure below. Because the entire Oesterdam is qualified as unsafe, this dune profile should be applied over the entire length of the dam.



Nature variant

The design aims to create a large area within the tidal range, mostly between -1m NAP and +1m NAP because this zone provides most benefit to nature. This intertidal flat restores the 1986 situation of the foreshore. A volume of sediment placed against the dam toe provides a buffer for the erosion over the intertidal foreshore during its lifetime of 50 years.

The optimal 2D location with regards to nature by creating a large intertidal area. That is why the nourishment is placed on the shallow Oesterdamflat, even extending further North and West in order to create as much intertidal habitat as possible. The figure above shows location 2 of the nature variant in green.

+4m NAP	Duttor mil	
+2m NAP	2 <u>950</u>	
+1m NAP		
-1m NAP	Ecologically interesting zone 1986	
-1.5m NAP		
-3m NAP		

Project variant

The group concluded that the project design is basically the nature variant with a euro factor. Because the project aim is to enhance safety and creating maximum benefit for nature, however with a budget restriction. The aim of this project design is therefore not to restore the foreshore back to the 1986 situation, but keep the current situation for the next 50 years. Another sacrifice made in order to keep costs down, is the total area that will be nourished. The nourishment will be smaller in the project design, location 3 (red), creating less intertidal area.



Group 4

Safety design

In this design the sand is placed close to the dam foot. The group concluded that the residual strength of the revetment is still considerable thus the dam in current condition will still withstand small waves. Therefore, the nourishment doesn't have to be above the design level of +4m NAP. Somewhat above HW, say +2.5m NAP, is probably sufficient to break the highest waves in order for the dam to withstand the reduced hydraulic conditions.



The necessary width of the buffer can be estimated using the lifetime of 50 years and the horizontal dune erosion rate. Suppose that with a steep slope of 1:3 the buffer will erode 0.5m/y in horizontal direction, the first estimated width of 50m is surely going to be sufficient.

If this design strategy is chosen, two basic designs are possible; either a wide low design or a smaller but high foreshore, see figures. These solutions are creating a high sandy beach so you are sacrificing intertidal area.

A problem for this design is that the design is above NAP, the nourishment is a beach, and it will not create intertidal flats. Intertidal area is sacrificed, the design is not beneficial for nature. In the reality this is not in line with the project goal and will therefore not be desirable nor feasible.

IV.5.1.1. Discussion/ remarks

- John: The high small design would sacrifice the least amount of intertidal area, if creating beach is unwanted this is best for nature. Because the least amount of intertidal surface is covered.
- Dick: Why is your design extended so far south along the Oesterdam? The group did this because the entire dam is 'rated unsafe'. Dick remarks that in this Southern area there is large lost of nature, as there are still salt marshes present there. While the erosion is not that large.



Nature design 'sausage of sand' ('little tent')

This design consists out of a general building block that looks somewhat like a small tent. The height of this block is 1m high and it is two times 50m wide, with two gentle slopes on both sides. This block functions both as a breakwater, breaking highest waves, and as reservoir, the sand will slowly spread across the adjacent flats.

With a total available volume of 600.000m3 of sand and a volume of 100m3 per meter length, this gives 6km length of these building blocks. This turned out to be surprisingly long, you could go twice along the dam within the project area and still have volume left. This gave many possibilities for the location.

The challenge is to place this 'sausage' in such a way that it will create maximum benefit for nature. As the Kreekrak foreshore bottom contains large amount of silt and lots of benthic life and erosion is small. This is not the best location for these building blocks to create nature. The Hooge Kraaijer flats makes more sense, because the soils is more sandy and erosion is high.

Three possible locations where defined.

1; On Hooge Kraaijer. Here the erosion is high. The sand will spread across flat compensating this erosion. Besides there is no great loss of nature at construction at this location, because the bottom is sandy without many benthic species.

2; On Oesterdam flat. For the same reasons as above. And because the shallow building blocks will break the high waves attacking the Oesterdam.

3; In the deeper water in front of the Kreekrak slik. By locating the nourishment here, the silty flat remains undisturbed while the foreshore will be nourished by the sediment spreading naturally over the flat.





Project design

This design combines providing safety with creating intertidal habitat. The same ridges as previous design are used. To act more as wave breakers they are now placed closer to the dyke.



Discussion/Remarks

- The wave breaking by these building blocks is very limited. Because the height is only 1 m it will not create a sufficiently shallow area where the waves will break. Especially if it is placed in deeper parts, such in front of the Kreekrak flat and/or during high water levels during storm. The design condition for the waterlevel is +4m NAP, with such large water depth the 1m high blocks will not have much effect.
- Are these small block not going to be eroded away very quickly? Eric; nourishment on Galgeplaat seems stable. Edwin; remember that in first 3yrs Galgeplaat nourishment lost 0.5m of height and that was large nourishment. Not small little exposed ridge with less 'body'. This will probably erode even faster.
- Mindert; What is the expected benefit for nature? Eric; Preservation of the flat behind.
 Sediment will be spread across flat behind compensating for the erosion. Also the block acts as wave breaker, reducing the erosion rate on flat behind. Remark; such a small ridge is not sufficient volume to nourish flat behind. Erosion over 50yrs is large and for large area you would need large volume to compensate.

IV.6 2nd design round - Building with Nature concepts

As there were only 30 minutes left for this second design round it is decided to change the approach. Everyone remains seated and the participants work in three larger groups to generate ideas for possible Building with Nature concepts.

Groups

- 1. Menno, Mindert, Edwin, Dick, Lies
- 2. Eric, Carla, Yvo, Dirk
- 3. Jaap, John, João

IV.6.1 1st group

Ridged hard structures, such as 'strekdammen' can act in two principal ways; blocking sediment transport or reducing the hydraulic conditions.

Blocking sediment transport

Blocking the sediment transport can happen in two directions. The first method is to restrict/reduce the alongshore sediment transport. This is done by placing one large cross shore 'dam' or other structure at the North of the Oesterdam flat. In this way blocking the assumed northern directed sediment transport. This in combination with small cross shore dams along the dyke. These dams will block the alongshore sediment transport without restricting any possible 'positive' transport cross shore towards the dam.

The second method is blocking the cross-shore transport. Placing a structure alongshore the Oesterdam, it will block the cross-shore transport completely. Including any possible 'building' transport towards the dyke.

These dams can be made out of BwN concepts, for example; oyster reefs, stones or wooden piles ('wilgenbos').



Breaking waves

Also floating structures, such as MosselZaadinvangInstallaties (MZIs), were considered as wave breakers. Question with these floating structures and other experimental concepts is whether they are effective in reducing the wave height.

Discussion/Remarks

Mindert; In the 'wilgenbos'- project, approximately 3 poles per m2, gave 80% reduction of 1m high waves over 30m width. These hanging structures will probably have the same effect. Currently the MZIs in the Eastern Scheldt are very open, and most likely too open to result in any reduction of the wave height.

Dick; Oyster reefs are not a good idea in the Eastern Scheldt and especially in the Kom. Because the Eastern Scheldt has a shortage of food, that is largest in the Kom. Currently the nutrients in the water (algae) are not sufficient and oyster would filter out this, leaving no/not sufficient food for cockles.

IV.6.2 2nd group

'Boomse' clay

This group was still thinking about the idea of group 4 in previous round, using sand ridges as building blocks. These ridges have to 'walk' into the desired direction onto the shoals and not towards the deeper water or channels. This means that the channel side of the ridge needs to be stabilized and protected against erosion. Ideas that generated were; oyster (no good as explained), stone protection (also not very innovative or beneficial to nature). Finally the group decided on using 'boomse klei' chunks. The project at Sluiskiltunnel ('geboorde tunnel') will make such chunks of clay available for use. This type of clay is very hard and the blocks could be used as armouring of the channel side of the slope.

Oyster shells

A second idea was to strengthen the sand by using oyster shells. With these shell banks could be created, which naturally present else in the Eastern Scheldt. These shell banks prevent erosion.

Discussion/Remarks

- John; in Hoorn there has been an experiment where shells have been mixed with sand, this experiment showed less erosion indeed.
- Oyster shells are cheap, they are waste from the oyster fishery industry. Currently they sell them to the 'grit' industry. Easily to get these shells, cheaper then sand.
- Dirk; Thinking that erosion around fixed ridges object is always large. Will this not give problems? The shells could be (partially) crushed to get a better grading. This would give a better results. With this mix of sand and crushed shells, the slopes could be steeper.
- Entire group is enthusiastic about this idea.

IV.6.3 3rd group

'Oesterrif hanger'

This idea is similar to the 'hanging beach'- project, the stacked oyster baskets act as a small wall that retains the sediment. The overall slope can therefore be steeper.

This project requires maintenance, the iron baskets will rust. If these old baskets are no longer sufficient new baskets will need to be constructed. This could be done by placing a new basket on top of old broken down baskets.

These oyster reefs make that the slope can be steeper. They might also break the waves, reducing erosion. However, still erosion at the flat behind so buffer still necessary yet it could be smaller.



IV.7 Attachment A: Hydraulic boundary conditions project area Normal tide

SWL = +3cm NAP	High Water (cm +NAP)	Low Water (cm +NAP)	Tidal range
Average tide	186	-160	346
Spring tide	214	-165	379
Neap tide	152	-139	291

1/3** year storm

Location	Wind speed	Wind direction	Water level	Hs (m)	T_Hs (s)
Oesterdam Flat	15 m/s *	~300 degrees *	+2.8m NAP *	1.0 *	4.2 *
Kreekrak Flat	15 m/s *	~300 degrees *	+2.8m NAP *	0.8 *	4.2 *

* Based on one year measurements at MRG station (2010)

** From frequency tables of potential wind speed at Vlissingen (1971-2000)

Design storm (1/4000 year)

Location	Wind	Direction (nautical)	Waterlevel	Hs (m)	Tp(s)
Oesterdam Flat	d=300 deg v=31 m/s	330	+4m NAP	2	5
Kreekrak Flat	d=300 deg v=31 m/s	315	+4m NAP	1.8	5

V. XBeach description

Description of the XBeach model partly copied from/after *{Van Thiel de Vries, 2009 #29}, *Manual, *2 articles.

V.1 Coordinate system and grid

In the coordinate system the computational x-axis is always oriented towards the coast, and the y-axis is directed alongshore (see Figure A.1). The coordinate system is defined relative to world coordinates (xw,yw) through the origin (xori,yori) and the orientation α 0, defined counter-clockwise with relation to the xw-axis (East).

The grid applied is a rectilinear, non-equidistant, staggered grid, where the bed levels, water levels, water depths and concentrations are defined in cell centers, and velocities and sediment transports are defined in u- and v-points, located at the cell interfaces. In the wave model, wave action, roller energy and radiation stresses are defined in cell centers, whereas radiation stress gradients are defined at u- and v-points.



Figure V-1 Coordinate system

V.2 Short wave formulations

Short wave transformation is obtained from a time dependent version of the wave action balance equation. Using a similar approach as in Delft University's HISWA model (Holthuijsen et al., 1989), the directional distribution of the wave action is taken into account whereas the frequency spectrum is represented by a single characteristic mean frequency.

The wave action balance is then given by:

$$\frac{dA_{w}}{dt} = \frac{\partial A_{w}}{\partial t} + \frac{\partial c_{g,x}A_{w}}{\partial x} + \frac{\partial c_{g,y}A_{w}}{\partial y} + \frac{\partial c_{g,\theta}A_{w}}{\partial \theta} = -\frac{D_{wave}}{\sigma}$$

The wave action A_w is defined as the wave energy for each frequency bin (θ). The dissipation of wave energy D_{wave} is both due to wave breaking and (if turned on, fw>0) due to bottom friction.

$$\frac{dA_{w}}{dt} = -D_{wavebreaking} - D_{wavefriction}$$

Where the loss of wave energy due to wavebreaking is calculated as follows,

$$\overline{D}_{w} = 2\frac{\alpha}{T_{rep}}Q_{b}E_{w}\frac{H_{rms}}{h}$$

where Qb is defined as;

$$Q_b = 1 - \exp(-(\frac{H_{mms}}{H_{max}})^n) \text{ default n=10}$$
$$H_{max} = \frac{\gamma \tanh kh}{k}$$

V.2.1 Surface rollers

Short wave energy dissipation serves as a source term to a roller energy balance. Similar to the wave action balance, the directional distribution of roller energy is taken into account whereas the frequency spectrum is represented by a single mean characteristic frequency. The roller energy balance is given by:

$$\frac{dS_r}{dt} = \frac{\partial S_r}{\partial t} + \frac{\partial c_{w,x}S_r}{\partial x} + \frac{\partial c_{w,y}S_r}{\partial y} + \frac{\partial c_{\theta}S_r}{\partial \theta} = -D_r + D$$

V.3 Long wave hydrodynamics and time averaged flow

For the low-frequency and mean flow the shallow water equations are applied. To account for wave induced mass-flux and subsequent return flow the shallow water equations are formulated in a depth-averaged Generalized Lagrangian Mean (GLM) formulation (Walstra et al., 2000). To that end the Eulerian shallow water velocities u_E and v_E (in *x*-direction and *y*-direction respectively) are replaced with the Lagrangian equivalent, u_L and v_L :

$$u^{L} = u^{E} + u^{S}$$
. where $u^{S} = \frac{E_{w} \cos \theta}{\rho hc}$

V.3.1 Advection-Diffusion equation

The sediment transport is modelled with a depth-averaged advection diffusion equation [Galappatti and Vreudgenhil, 1985].

$$\frac{\partial hC}{\partial t} + \frac{\partial hCu^{E}}{\partial x} + \frac{\partial hCv^{E}_{r}}{\partial y} + \frac{\partial}{\partial x}[D_{h}h\frac{\partial C}{\partial x}] + \frac{\partial}{\partial y}[D_{h}h\frac{\partial C}{\partial y}] = \frac{hC_{eq} - hC}{T_{s}}$$

The concentration C is determined by the advection-diffusion equation where an equilibrium concentration is used. This Ceq is a function of wave stirring etc. and gives the capacity of the water column with its hydrodynamic conditions (waves, currents) to hold a certain concentration. When the actual concentration C is lower then this Ceq, the water will take up

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sediment from the bottom. Other way around when C>Ceq, sediment will be deposited. So Ceq-C is a source/sink term for the sediment concentration.

$$C_{eq} = \frac{A_{sb} + A_{ss}}{h} \left(\left(\left| u^{E} \right|^{2} + 0.018 \frac{u_{rms}^{2}}{C_{d}} \right)^{0.5} - u_{cr} \right)^{2.4} \left(1 - \alpha_{b} m \right)$$

V.3.2 Sediment transport and bed updating Sediment transport S is calculated from the advection and diffusion of sediment. The sediment transport can be split into suspended transport and bedload sediment transport, using a factor C or Cbed.

$$\begin{split} S_{x,y} &= S_{suspended} + S_{bedload} \\ S_{suspended} &= C * v_{rep,S} * h - D_c * h * \frac{dCs}{dy} - slope factor \\ S_{bedload} &= C_{bed} * v_{rep,bed,S} * h - slope factor \end{split}$$

Gradients in sediment transport cause a change in bathymetry. The bed is updated using:

$$\frac{dz_b}{dt} = \frac{f_{mor}}{(1-p)} * \frac{dS}{d\bar{x}}$$

VI. Sensitivity analysis

On original Osituation and on initial profile. During 1/1yr conditions with meaning with tide. To represent real sensitivity during lifetime, with changing water levels.

VI.1 0 situation

To represent erosion of foreshore, between 400 to 1200. The sharp edge will probably adapt due because not smooth initial profile.



Figure VI-1 Bathymetry current foreshore Oesterdam (Broad Flat) + Oesterdam

VI.1.1	Sensitivity	Hs vs	Waterlevel
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Input	Run1	2	3	4	5	6	7	8
Tide	Normal,			Normal,		Tide=0		
	surge0			surge 2				
Waves	Hs=4	Hs=1	Hs=0.05	Hs=4	Hs=1	Hs=4	Hs=1	Hs=0.05



Figure VI-2 Cumulative sedimentation/erosion of foreshore during normal tide conditions with varying wave heights. RED=Hs4, GREEN=Hs1, BLACK=Hs0

Wave height is very important, only with high waves (Hs=2, RED), significant changes bed level during normal tide. Most erosion on edge, deposition further onto flat .



Figure VI-3 Cumulative sedimentation/erosion during constant waves Hs=4, varying water level timeseries RED=Normal tide, BLUE=Tide+2msurge, PURPLE=Constant 0m NAP.

Normal tide (red) shows most bedlevel change on edge of flat. High waves during waterlevels <0m NAP attack this edge.

Over stretch of flat (between 500-1100) no large differences.





Very small bedlevel changes with these smaller waves, Hs=1. Again, with normal tide (Red) most changes on edge flat



Figure VI-5 Cumulative sedimentation/erosion (e-4!)during constant wave height Hs=1 varying tide/surge. RED=surge0, BLUE=surge2, GREEN=tide0

With surge2m (Blue) no erosion. Because small waves (Hs=1) no effect bottom With surge0m (Red), erosion edge of flat. no change on flat. With tide0 (Green), erosion over flat, but very small (0.1mm!)

VI.1.1.1 Conclusions waves and tide

Erosion near dam toe, erosion edge of flat deposited on slope and in channel. Erosion on actual flat is low.

Waves are most important for the erosion.

Note, Hs=4 is very extreme! not realistic, even design conditions of 1/4000 have waves Hs=2m.

VI.1.2 Sensitivity Sediment D50 and D90

Choosing most extreme case above, to see most difference in bedlevel change.

Input	Run1	2	3
Tide	Normal	Normal	Normal
Wave	Hs=4	Hs=4	Hs=4
Sediment D50	200 (default)	100	50**
Output	Red	Blue	Green

** Rounded to 100 mu m?? But then why diff?



Figure VI-6 Cum Sed/Erosion with Hs=4, waterlevel=Normal tide varying D50. RED=D50=200, BLUE=D50=100, GREEN=D50=50.

With small D50 (green) sediment is deposited further on flat (Ts, adaptation time is function of ws).



Figure VI-7 Cum. Sed/Erosion, Hs=4, Normal tide, D50=100. Varying D90. BLUE=D90=300, RED=D90=500.

Large D90 (RED), ucr becomes smaller. Indeed more transport. Note, not as with very small D50 sediment transported further, just more transport, more extreme sed.ero.

VI.1.2.1 Conclusions sediment type

Changing D50 and D90 shows differences in bedlevel change, but not as extreme as influence waves/water levels.

With found most erosive conditions (Hs4, tide normal, D50 50 mum)



Figure VI-8 Cum Sed/Erosion, Hs=4, Tide normal, D50=50. Blue=12hrs, Red=24hrs, Purple=36hrs.



Figure VI-9 Cum Sed/Erosion, Hs=4, Tide normal, D50=50. Blue=12hrs, Red=24hrs, Purple=36hrs.

Erosion edge of foreshore continues. But erosion on flat itself.. after 800 doesn't change much in time.

Between 0-400 is adaptation. But between 400-600 might be actual erosion that continues during tidal cycles. That is where waves break. Notice also building of flat between 550-800.

VI.1.3 Sensitivity wind speed (?)

Hard to compare, due to diff waves, random jonswap spectrum .

Input	Run1	2	3
Tide	Normal	Normal	Normal
Wave	Hs=4	Hs=4	Hs=4
Sediment D50	100	100	50**
Wind	0	5 m/s	20 m/s
Output	Red	Blue	Green

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Figure VI-10 Sensitivity wind speeds. Tide=Normal, Waves=Hs4,Tp5 RED=D50=100, Windv=0m/s, BLUE=D50=100, Windv=5m/s, GREEN=D50=50, Windv=20m/s.



Figure VI-11Sesitivity windspeeds Osituation, zoomed in

Difference during tide; More sed. transport with wind during lower water levels. Both higher max as lower min. Does this mean more extreme? due to wind both concentration and currents changed!

Higher wind, more concentration=more extreme transport During rising tide, wind same direction. More onshore transport. During falling tide, wind other direction, less offshore/more onshore??

VI.2 BufferLow

Simulating one tidal cycle on the initial buffer low profile

Buffer Low	Run1	Run2	Run3	Run4	Run5	Run6
D50 (mu m)	100	150	250	150	150	150
Hs (m)	1	1	1	1	2	3

VI.2.1 Hs



Figure VI-12 RED=Hs1, BLUE=HS2, GREEN=HS3





Figure VI-13 Red=D50=100, BLUE=D50=150, GREEN=D50=250.

Changes in buffer profile are not that extreme. Order of mm. The changes in bedlevel are small. The slope is also relatively gentle (1:65) and is not showing large deformations.

Note that this is during one tidal cycle. For 50 years development this could mean still some significant changes in the bedlevel development. However, the adaptation of the profile is expected to decrease in time. Therefore differences will not increase linearly in time.

VI.3 Buffer Small

Small Buffer	Run1	Run2	Run3	Run4	Run5	Run6
D50 (mu m)	100	150	250	150	150	150
Hs (m)	1	1	1	1	2	3

VI.3.1 Hs



Figure VI-14 Sensitivity of the Small buffer profile to changes in Hs

VI.3.2 D50



Figure VI-15 Sensitivity of Small buffer design to changes in D50

VI.4 Flat

Flat	Run1	Run2	Run3	Run4	Run5	Run6
D50 (mu m)	100	150	250	150	150	150
Hs (m)	1	1	1	1	2	3

VI.4.1 D50

Changes in the adaptation of the bed level at the edge of the flat profile are more sensitive to different D50 and Hs. Order of centimetres. This is also because initial changes in the bed level are relatively large. Because the slope is relatively steep (1:25) there is much change in bed level initially.



Figure VI-16 GREEN D50=250, BLUE D50=150, RED, D50=100



Figure VI-17 D50; Green_250, Blue150, Red=100

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VI.4.2 Hs



Figure VI-18Hs green=3, red=2, blue=1



Figure VI-19 Hs green=3, red=2, blue=1